

“Silver” mode for heavy Higgs searches in the presence of a fourth SM family

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Abstract

We investigate the possible enhancement to the discovery of the heavy Higgs boson through the possible fourth SM family heavy neutrino. Using the channel $h \rightarrow \nu_4 \bar{\nu}_4 \rightarrow \mu W \mu W \rightarrow \mu jj \mu jj$ it is found that for certain ranges of the Higgs boson and ν_4 masses, LHC could discover both of them simultaneously with 1fb^{-1} integrated luminosity.

1 Introduction

The hunt for the Higgs boson is the main aim of the LHC to complete the validation of the basic principles of the Standard Model (SM). The main production mechanism of the Higgs boson at hadron colliders is the gluon fusion via heavy quark loop. Therefore the number and nature of the quarks contributing to that loop play a crucial role. In the realm of the SM as we know it today, with 3 families, the main contribution is from the top quark. However, the number of families in the SM is a free parameter and the LEP-1 data fixes only the number of fermion families with a light ($m_\nu < m_Z/2$) neutrino. The EW precision data, on the other hand, favor the 3 and 4 family cases equally [1]. Moreover a fifth and even a sixth family may be allowed depending on the precision measurements on W boson properties. On the other hand, the upper limit on the number of families comes from the asymptotic freedom property of the QCD as 9.

If there is a fourth SM family, as also implied by the flavour democracy hypothesis (see [2] and references therein), its quarks are expected to be heavier than 250 GeV, contributing to the Higgs boson production loop in addition to the top quark. Such a contribution enhances the production cross section for the Higgs boson and makes the gluon fusion channel sensitive to new physics. Recently at the Tevatron, the process $gg \rightarrow h \rightarrow WW^*$ is investigated after taking into account the possible enhancement due to a fourth SM family [3]. This mode is the most promising for the Higgs masses between 130 and 190 GeV both at the Tevatron and the LHC. However, its observation at the Tevatron requires the enhancement from the fourth family.

At the LHC, in three SM family case, for a heavy Higgs of mass between 200 and 500 GeV the most prominent mode is the “golden” mode : $gg \rightarrow h \rightarrow ZZ \rightarrow \ell\ell\ell\ell$. For an even heavier Higgs, between 500 and 800 GeV, the “semi-golden” mode, $gg \rightarrow h \rightarrow ZZ \rightarrow \ell\ell \nu\nu$ becomes the preferred mode of discovery. Above 800 GeV, the discovery channel has to be the $gg \rightarrow h \rightarrow WW \rightarrow \ell\nu jj$ [4]. The fourth SM family quarks would increase the production cross section by a factor between 5 - 8 depending on the Higgs boson mass [5] decreasing the required luminosity for a 5σ discovery.

The other fourth family members, depending on their mass, could also allow new search channels for the Higgs boson. In this note, we argue that the $gg \rightarrow h \rightarrow \nu_4 \bar{\nu}_4 \rightarrow \ell W \ell W$ channel, called hereafter the “silver” mode, could be competitive with the golden mode for some region of the Higgs and ν_4 masses. Fig. 1 contains the Feynman diagrams of the golden and silver channels for the Higgs boson discovery.

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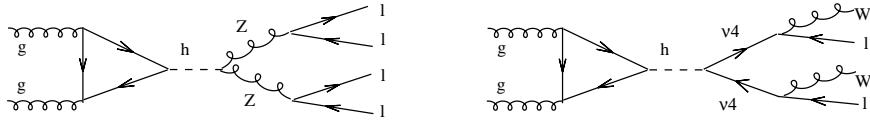


Figure 1: The “golden” (left) and the “silver” (right) modes for heavy Higgs boson discovery.

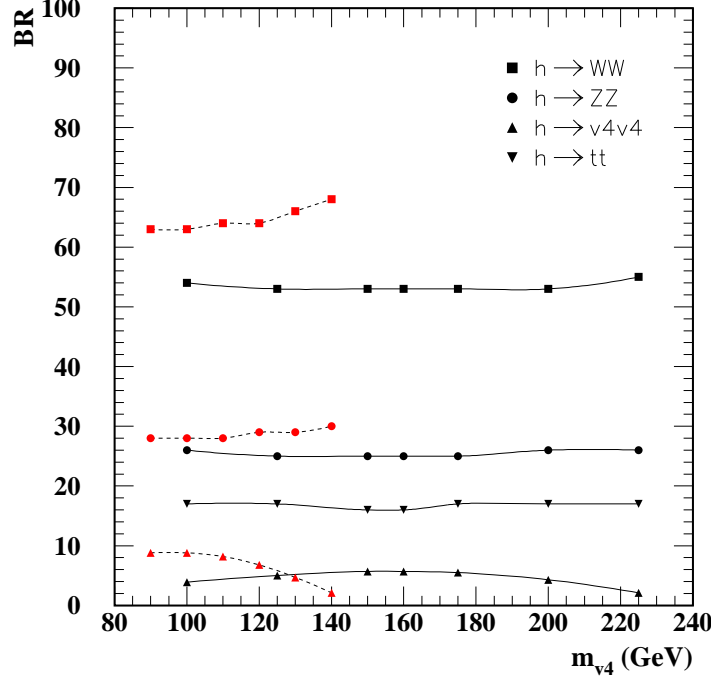


Figure 2: The heavy Higgs branching ratios as a function of the heavy neutrino mass for two example m_h values 300 GeV (dashed lines) and 500 GeV (solid lines)

2 Fourth family neutrino pair production and decay as the “silver” mode

The fourth family neutrino, ν_4 , couples to the Higgs boson with a vertex coefficient proportional to its mass providing a new decay channel. The branching ratios as a function of the ν_4 mass for two Higgs mass values, 300 and 500 GeV, are presented in Fig. 2. As seen $\text{Br}(h \rightarrow \nu_4 \bar{\nu}_4)$ is maximized between 90 and 100 GeV as 8.8% for $m_h = 300$ GeV and between 150 and 160 GeV as 5.7% for $m_h = 500$ GeV. Below we compare the “golden” and “silver” modes in these mass ranges.

The decays of the ν_4 are governed by the leptonic 4×4 CKM matrix. For numerical calculations, we consider the parameterization in [6] which is compatible with the experimental data on the masses and the mixings in the SM leptonic sector. In this case, the $\text{Br}(\nu_4 \rightarrow \mu W) \simeq 0.68$ and $\text{Br}(\nu_4 \rightarrow \tau W) \simeq 0.32$ which imposes the main discovery signal as two muons and four jets considering the hadronic decays of the W bosons in the final state. Note that the “silver” mode contains only muons compared to both electrons and muons of the “golden” mode. This scenario with $m_h = 300$ GeV, leads to $\text{Br}(h \rightarrow \nu_4 \bar{\nu}_4 \rightarrow \mu^+ \mu^- jjjj) = 1.22 \times 10^{-2}$ which should be compared to the “golden” mode branching ratio of 1.12×10^{-3} , giving an enhancement factor about 11. Corresponding numbers for $m_h = 500$ GeV are 1.88×10^{-2} and 1.25×10^{-3} respectively, yielding an enhancement of about 15 times. We believe that an order of magnitude higher statistics would compensate the possible inefficiencies associated with jet detection and hadronic W reconstruction.

An associated channel to the “silver” mode is the case where one of the W boson decays leptonically: $W \rightarrow \ell \nu$ ($\ell = \mu, e$). The final state in this case will be $\mu^+ \mu^- \ell jj \cancel{E}_T$. The number of such events is 63% of the “silver” mode discussed above, bringing the total enhancement factor up to 24 (18) compared to the “golden” mode for a Higgs boson of $m_h = 500$ (300) GeV.

If the fourth family neutrino is of Majorana nature, an experimentally clear signature would be available, namely same sign muons as decay products of ν_4 s. Although in this case, the number of expected signal events is halved, the SM background is practically negligible making this mode deserve the name “platinum” mode.

3 Conclusion

If Nature allows, a double discovery in the first year of the LHC start up is in the realm of the possible: the fourth family neutrino and a heavy ($m_h > 300$ GeV) Higgs boson. For $m_h = 300$ (500) GeV the fourth family quarks increase the Higgs production cross section to 7×10^4 (2.5×10^4) fb compared to 10^4 (5×10^3) fb in the 3 family SM case [7]. Consequently, the so called “silver” mode allows about 850 (470) Higgs bosons (and obviously twice as many ν_4) to be reconstructed with 1fb^{-1} luminosity for $m_h = 300$ (500) GeV and $m_{\nu_4} = 100$ (150) GeV. The Monte Carlo simulation to verify this statement is under progress.

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Note added: After the submission of the first version of this note, an arXiv entry made one month ago, mentioning an enhancement to Higgs discovery from $h \rightarrow \nu_4 \bar{\nu}_4 \rightarrow \ell W \ell W \rightarrow 4\ell + \cancel{E}_T$ channel was brought to our attention [8].

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